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# The Stability of Strategic Earth Penetrators—The DSP-300 Field Test Series (U)

A. R. Ortega
Thermal and Fluid Mechanics Division
Sandia National Laboratories
Livermore, CA. 94551-0969

## Abstract (U)

During the 1960s and 1970s, hundreds of earth penetrator field tests were conducted into soil. In general, this database applies to penetrators with relatively high length-to-diameter ratios (L/Ds), and it indicates that high L/D penetrators follow stable trajectories in soil targets. Strategic earth penetrators packaged in reentry vehicles can result in penetrator designs with low L/Ds. Therefore, in order to extend the previous technology database, the DSP-300 field test series was initiated to investigate the stability of low L/D penetrator designs. One-half scale model penetrators were fired into a soil target using Sandia's Davis gun. Test results indicated that strategic earth penetrators of recent interest to SNLL and LLNL were stable for anticipated worst-case impact conditions. In addition, a minimum taper angle of 1° was established as a design criterion for tapered afterbody penetrators.

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# Contents

# List of Tables

# Nomenclature

| | |
|---|---|
| CG | Center-of-gravity (% of overall length referenced from nose tip) |
| CRH | Caliber radius head, tangent ogive nose shape. For a 3 CRH tangent ogive nose shape, the radius of the circular arc defining the nose contour is equal to 3 times the outer diameter at the tangent point, i.e., the intersection point between the nose and afterbody. |
| DSP | Davis gun Strategic earth Penetrator |
| L/D | Length-to-diameter ratio. For penetrators with tapered afterbodies, the diameter at the midpoint of the afterbody was used. |
| W/A | Weight-to-cross sectional area ratio. For penetrators with tapered afterbodies, the area is based on the diameter at the midpoint of the afterbody. |

## 2 Experimental Procedure

The DSP-300 field test series utilized Sandia's Davis gun to evaluate stability of low L/D earth penetrators. This 12 inch inner diameter, smooth-bore recoilless cannon (Figure 1) accelerated 1/2-scale model uninstrumented penetrators to steady impact velocities. Due to the fact that the penetrator had a smaller diameter than the gun bore, the penetrator afterbody was supported with a polyurethane foam sabot (density=15 lb/ft$^3$) and a 4340 steel pusher plate that fit the inner diameter of the gun barrel (Figure 2). Projectile velocity and attitude (pitch plane only) were recorded with 2 image motion or streaking cameras, one focused near the barrel muzzle and the other aimed several feet from the impact point. (See Figure 3 for typical photographic results.) Following impact and penetration of the target, the trajectory was reconstructed and penetrator recovered by drilling several vertical shafts.

All DSP-300 series tests were conducted into Antelope Lake, a dry hard clay lake bed, located at Sandia's Tonopah Test Range (TTR), Nevada. Although Antelope Lake is relatively homogeneous for a natural geology, a soil testing program was initiated to characterize the target site concentrating on the near surface soil layers (<50 feet). The target was cored and mechanical property tests were performed by the U. S. Army Waterways Experiment Station [8]. Appendix A contains the TTR coordinates of the coring site as well as the impact points of all tests performed.

Worst-case impact conditions anticipated for the SNLL/LLNL strategic earth penetrator program were: an impact velocity of 2500 ft/sec, an impact angle of 45° and an angle of attack equal to 2° (nose up). (Refer to Figure 4.) Impact conditions for the DSP-300 test series were parameterized as follows: impact velocities from 1940 to 2560 ft/sec, impact angles from 20° to 45°, and angles of attack from 0° to 4° (nose up). Every penetrator evaluated in this study was tested at impact conditions equal to or more severe than worst-case conditions.

Beginning with the 1982 preliminary design, the external shape and mass properties of penetrators jointly agreed upon between SNLL and LLNL changed significantly over a period of several years. This was primarily due to packaging of various nuclear physics package envelopes and internal components. The stability of these penetrators was investigated in this test series as they evolved.

Figures 5–11 contain drawings of all the 1/2-scale model penetrator designs tested in this study.[1] These penetrators had 3 CRH tangent ogive noses, which was a compromise between a more blunt shape (better for packaging and stability) and a more pointed configuration (better for loads and penetrability). Although the external dimensions of each penetrator reflected a 1/2-scale replica, the wall thickness was

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[1] The pertinent scaling laws are summarized in Appendix B.

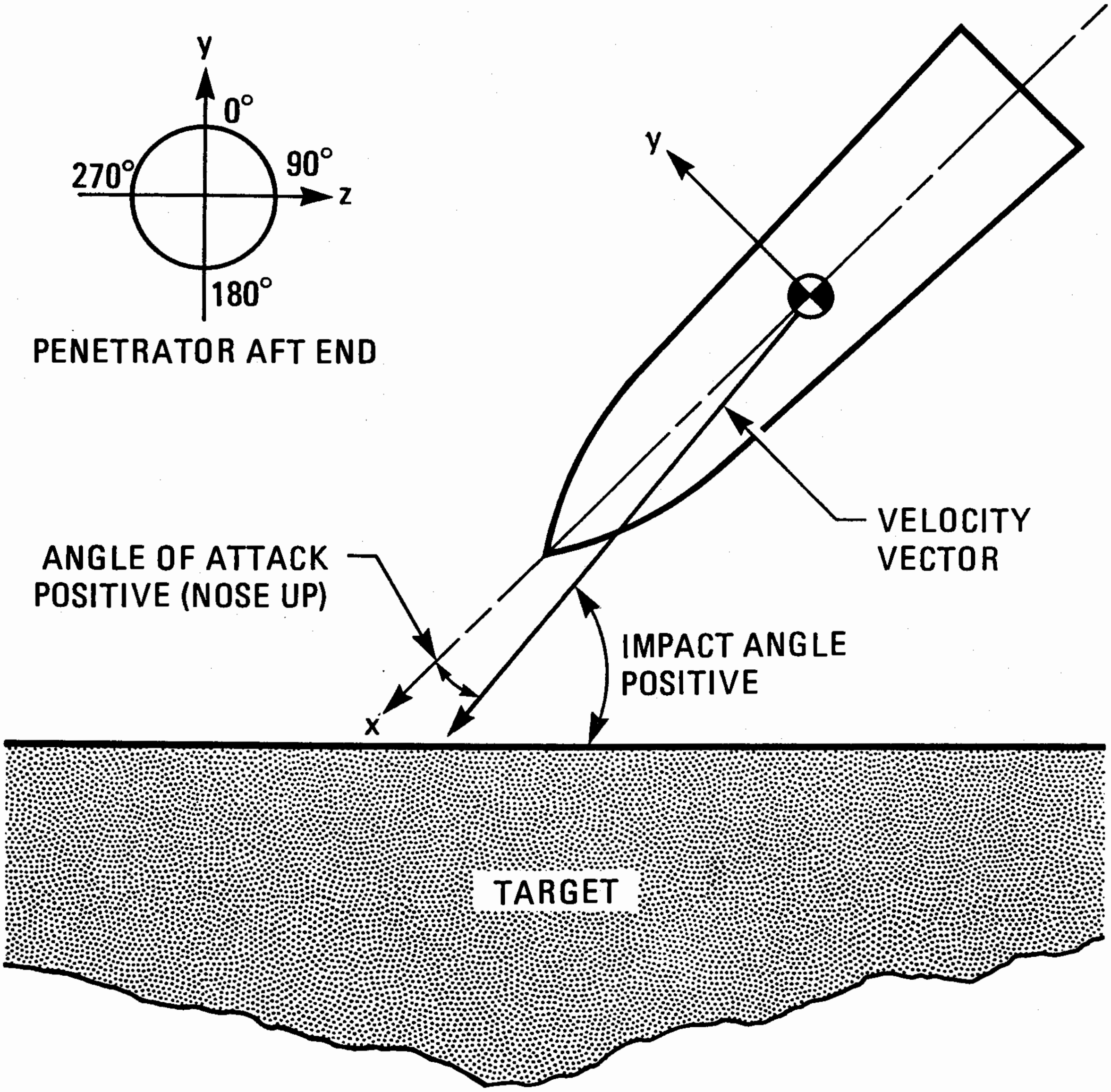

Figure 4: Definition of penetrator impact conditions. The x-y and x-z planes are the pitch and yaw planes, respectively.

# 3 Test Results

General observations concerning the post-test penetrator condition will be addressed first. This will be followed by the results from the individual tests grouped according to design.

## 3.1 Post-test Penetrator Condition

All penetrators tested resulted in negligible steel removed from the nose and very little wear on the afterbody. In addition, a patch of paint just aft of the nose was still evident following tests of cylindrical afterbody penetrators. Due to this excellent post-test condition, most penetrators tested were reused in subsequent Davis gun shots.

During penetration, the 12 inch diameter steel pusher plate (initially attached with 2 each #10–32 screws at 90° and 270°) is stripped from the smaller diameter penetrator. For oblique impacts, the pusher plate rotates and may slap the penetrator aft end causing localized plastic deformation. Post-test observations indicated this occurred in all 0° angle of attack tests, but in only 50% of the non-zero angle of attack tests. This deformation varied circumferentially between 0° and 360°. In only one test was there a strong possibility that the trajectory was significantly influenced by this phenomenon. (See DSP-309 test results.)

## 3.2 DSP-301, 302, 305 and 306 Results

The penetrator design associated with the above 4 tests is shown in Figure 5. This joint SNLL/LLNL strategic earth penetrator, known as the 500SI design, evolved from the preliminary 1982 concept [9]. Packaging the primary and secondary envelope resulted in a 55% CG and an afterbody taper angle of approximately 2.5°.

Figures 12–15 contain the impact conditions and trajectories for DSP-301, 302, 305 and 306.

DOE b(3)
DOD b(3)

[redacted]

A 3/4-scale model of the 500SI design (DSP-202) was tested into Antelope Lake, TTR at almost identical impact conditions as DSP-301. The objective of comparing DSP-202 with DSP-301 was to investigate the affect of scaling on stability. As anticipated, good agreement was obtained between the two tests, i.e., both trajectories were similar [10].

DOE b(3)
DOD
b(3)

## 3.4 DSP-312 and 316 Results

DOE b(3)

DOE b(3)

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[2] The lateral (yaw) deviation observed in this test may have been influenced by (1) pusher plate impact with the penetrator aft end, and (2) improper alignment of the penetrator in the gun barrel. The DSP-312 penetrator/sabot assembly rotated while raising the assembly in the Davis gun. This changed the penetrator preset angle of attack from 2° (pitch)/0° (yaw) to about 1.9° (pitch)/0.5° (yaw).

## 3.5 DSP-309 and 315 Results

Low taper angle physics package envelopes result in earth penetrators having relatively forward CGs and low afterbody taper angles compared to the B1 penetrator. However, based on the previous penetrator technology database, it was speculated that low L/D cylindrical afterbody penetrators were unstable in soil [redacted]

DOD b(3)

In order to specifically address the affect on stability of varying the afterbody shape, the DSP-309 penetrator (Figure 7) had an identical CG and weight as the 500SI design, but the afterbody was cylindrical. DSP-309 was the only test where significant damage to the penetrator aft end occurred due to pusher plate impact at the 0° location. This phenomenon probably influenced the peculiar trajectory for DSP-309 shown in Figure 22, where deviation downward from a straight-line path is evident. It is believed that the downward turning trajectory was caused by (1) the penetrator being unstable for these impact conditions, and (2) the pusher plate impact at 0° forcing the penetrator to turn ~~nose dowr~~

[redacted]

DOE b(3)
DOD b(3)

### 3.6 DSP-311 and 317 Results

Packaging a low taper angle physics package envelope resulted in the A2 penetrator, a design of recent interest to both SNLL and LLNL. This penetrator had a L/D=4.9, an afterbody taper angle of 1.05° and a CG=52%. The 1/2-scale model DSP-311/317 design[3] is shown in Figure 9.

DOE
b(3)

[redacted]

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[3] The taper angle for DSP-311/317 was machined to 1.00° rather than 1.05°.

## 5 Appendix A

Table 2: TTR coordinates of DSP-300 series impact points

| TEST | TTR Coordinates * | |
|---|---|---|
| | X (ft) | Y (ft) |
| 301 | 14611 | -54941 |
| 302 | 14454 | -55095 |
| 303 | 14494 | -54969 |
| 304 | 14442 | -54969 |
| 305 | 14178 | -54935 |
| 306 | 14140 | -54949 |
| 307 | 14555 | -54882 |
| 309 | 14214 | -54890 |
| 310 | 14193 | -54910 |
| 311 | 14409 | -54844 |
| 312 | 14364 | -54877 |
| 315† | - - - | - - - |
| 316 | 14086 | -54897 |
| 317 | 14048 | -54939 |
| coring site | 14492 | -54877 |

* x=0, y=0 is center of TTR main target

† Impact point was not surveyed on this test.

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